URA Review, March 14-15, 2003

Theoretical Physics Department

R. Keith Ellis

OUTLINE

1. Personnel
2. Visitor programs
3. Community outreach and service
4. Current research

Theoretical Physics Department Personnel 2002/2003

Scientists(11)

Bill Bardeen
Marcela Carena
Estia Eichten
Keith Ellis
Walter Giele
Chris Hill
Andreas Kronfeld
Joe Lykken
Paul Mackenzie
Stephen Parke
Chris Quigg

Associate Scientists(3)

Bogdan Dobrescu
Ulrich Nierste
Yasunori Nomura

Frontier Fellows(5)

Ken Lane (2002)
Steve Gottlieb (2002)
Ulrich Baur (2002)
Scott Willenbrock (2002)
Aida El-Khadra (2002)

Distinguished Guest Scient.(1)

Boris Kayser

Research Associates(8)

G. Barenboim	Ayres Freitas	Andre DeGouvea
Ulrich Haisch	(Adam Leibovich)	Eduardo Ponton
Masataka Okamoto	Zack Sullivan	Tim Tait

Users

C. Albright (NIU)	Alex Kagan(Cincinnati)
Y. Keung (UIC)	A. El-Khadra (Illinois)
S.P. Martin (NIU)	Ulrich Baur (Buffalo)

Personnel Changes

- Post-doc movements Fall 2003
  Adam Leibovich→ Pittsburgh (Asst. Prof)
  Gabriela Barenboim→ (Valencia?)

- New Hires Fall 2003
  Olga Mena (from Madrid),
  Giulia Zanderighi (from Durham)

- Associate Scientists (2 hired in the last cycle)
  Ulrich Nierste arrived 01/2002
  Bogdan Dobrescu arrived 08/2002
  Yasunori Nomura arrived 11/2002

- History of the post-docs, associate scientists and Frontier Fellows is posted on the web.
  http://theory.fnal.gov/people/ellis/alumni.html
  http://theory.fnal.gov/people/ellis/Assoc.html
  http://theory.fnal.gov/people/ellis/frontier.html

Visitor program

The visitor program has long been part of the Fermilab theory group.

- Frontier Fellows Senior distinguished visitors spending research time at the Frontier.
  About 5 in 2002/2003
- Summer visitors About 30 visitors spending about one month during the summer.
- Short term visits, Scientific collaborators and workshop participants
- Speakers
  Theoretical seminar (53 speakers in 2002)
  Joint Experimental-Theoretical Seminar
  (44 talks in calendar 2002).

Frontier Fellows

The frontier fellowship allows active senior physicists to spend time at Fermilab unencumbered by the burden of teaching.

- Vernon Barger (10/98-12/98)
- Thomas Appelquist (10/98-12/98)
- Howard Haber (09/98-12/98)
- Pierre Ramond (06/99)
- Stuart Raby (02/99-06/99)
- Steve Ellis (03/00-06/00)
- Wu-Ki Tung (02/00-06/00)
- Moshe Moshe (3/00-9/00)
- Pierre Ramond (5/00)
- Stefan Pokorski (9/00-12/00)
- Mariano Quiros (9/00-12/00)

- Jo Anne Hewett (9/00-12/00)
- Alexei Yu. Smirnov (4/01)
- Mariano Quiros (9/01-12/01)
- Steve Gottlieb (9/01-6/02)
- Ken Lane (9/01-2/02)
- Ulrich Baur (2/02-4/02)
- Eric Braaten (10/02-12/02)
- Scott Willenbrock (7/02-12/02)
- Aida El-Khadra (7/02-12/02)

Community service

- Carena NSERC Grants committee, Canada
  Linear collider octet.
- Dobrescu Director's Fixed target review.
- Eichten APS investment sub-committee
- Ellis Scientific program sub-committee, LP2003
- Hill Saturday morning physics, VLHC workshop
- Kayser P5, Academic lectures
- Kronfeld Linear collider octet.
- Lykken PAC, EPAC, TASI, MUTAC, Aspen
- Mackenzie DOE SciDAC, Natn'l committee
  Advisor to KEK on large scale simulation
- Parke Co-organizer: Nuhorizons, Academic lectures
- Quigg Past chair of DPF, HEPAP,
  Program committee APS Albuquerque 2002
  (chair), IMSA Board

Current research

Lattice gauge

Bardeen, Eichten, Kronfeld, Mackenzie, Okamoto

Supersymmetry

Carena, Nierste, Freitas

Linear Collider

Kronfeld, Freitas

Perturbative QCD

Ellis, Giele, Sullivan

Flavor Physics

Bardeen, Eichten, Leibovich, Nierste, Haisch, Quigg

Neutrino Physics

Barenboim, DeGouvea, Kayser, Parke, Quigg

String Theory, D-branes, Extra dimensions

Carena, Lykken, Tait, Hill, Nomura, Ponton

Model building

Dobrescu, Hill, Nomura

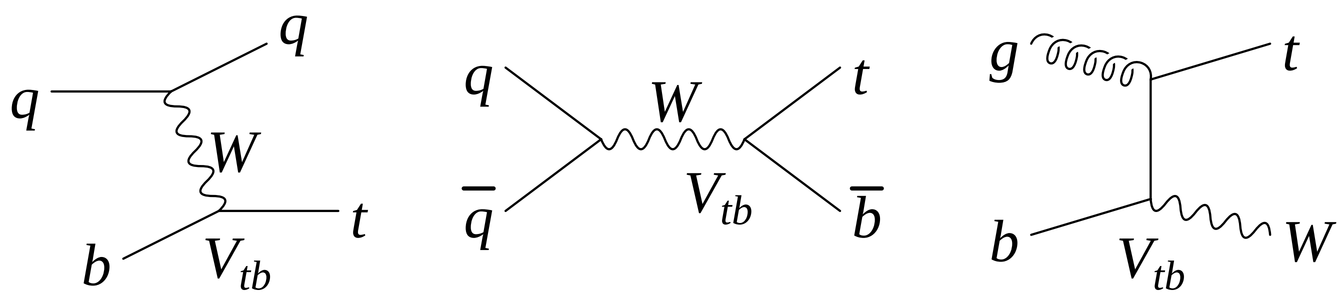
QCD and hard scattering

Sullivan, Ellis, Giele

- Parton distributions with uncertainties(Giele)
- A large effort on Monte Carlo programs giving NLO predictions for many processes of interest. e.g. Normalization of W+4 jets?
- MCFM, unified NLO program, (Ellis),
  New processes in 2002,W/Z+2-jets, H+1-jet, $W/Z\gamma$, see http://mcfm.fnal.gov
- Single top production (Sullivan)

Single Top production

Sullivan



- A measurement of V_{tb} comes from top production, not top decay
- Extraction of V_{tb} requires knowledge of cross section.
- Updated cross sections are updated with CTEQ5M1 PDFs:
- Note that at Tevatron cross sections are of a similar size as $t\bar{t}$-production.

	Tevatron, Run I	Tevatron, Run II	LHC
$\sigma_t^{\mathrm{NLO}} =$	1.45 ± 0.08 pb	1.98 ± 0.13 pb	247 ± 12 pb
$\sigma_s^{\mathrm{NLO}} =$	0.75 ± 0.07 pb	0.88 ± 0.09 pb	10.7 ± 0.9 pb

- PDF uncertainties are calculated:
  add $\pm 15\%$ in t-channel, $\pm 4\%$ in s-channel.

- All old CTEQ and MRS sets had bad b PDF.
  CHANGE: $\delta\sigma_t$: -15%, -13%, $+1\%$, $\delta\sigma_s$: $+3\%$, $+4.5\%$, $+5\%$.

- A 1.96 TeV Tevatron will produce 4–10% fewer events in all high mass channels than predicted for 2.0 TeV.

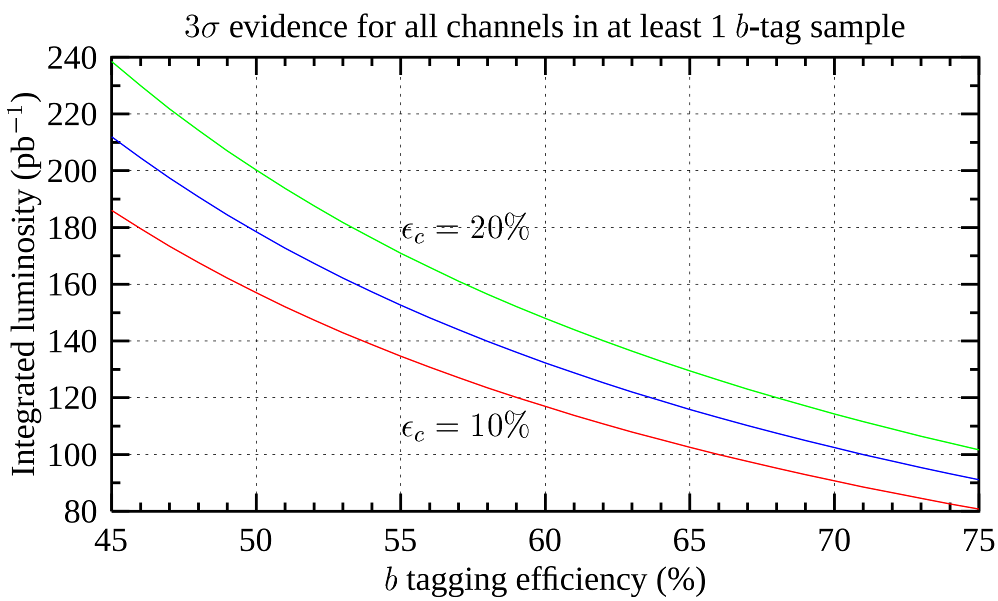
- Fully differential NLO QCD corrections to $t + 1$ jet

Integrated luminosity to see single-top

First look in the at least 1 b-tag sample.

$(bj\ell\not{E}_T + bb\ell\not{E}_T)$

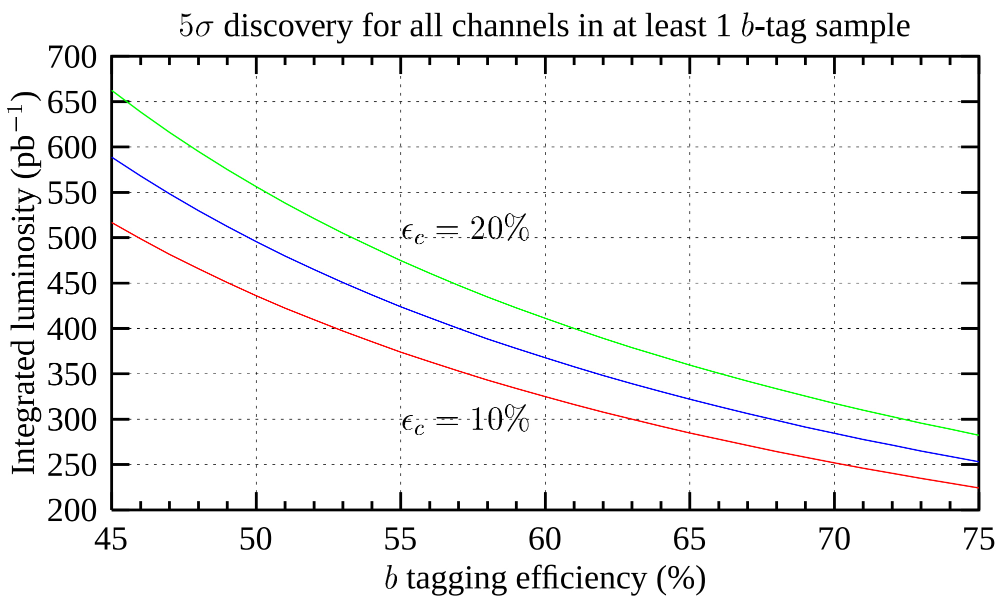
Apply a jet veto: i.e. do not allow more than 2 high E_T jets.



130 pb^{-1} for 3σ evidence of single top $(t + s + Wt)$

Good b-tagging efficiency is vital.

5-σ discovery



- 370 pb^{-1} for 5σ discovery of single top $(t + s + Wt)$
- 11% measurement of V_{tb} with two inverse femtobarns

Supersymmetry and Rare B Decays

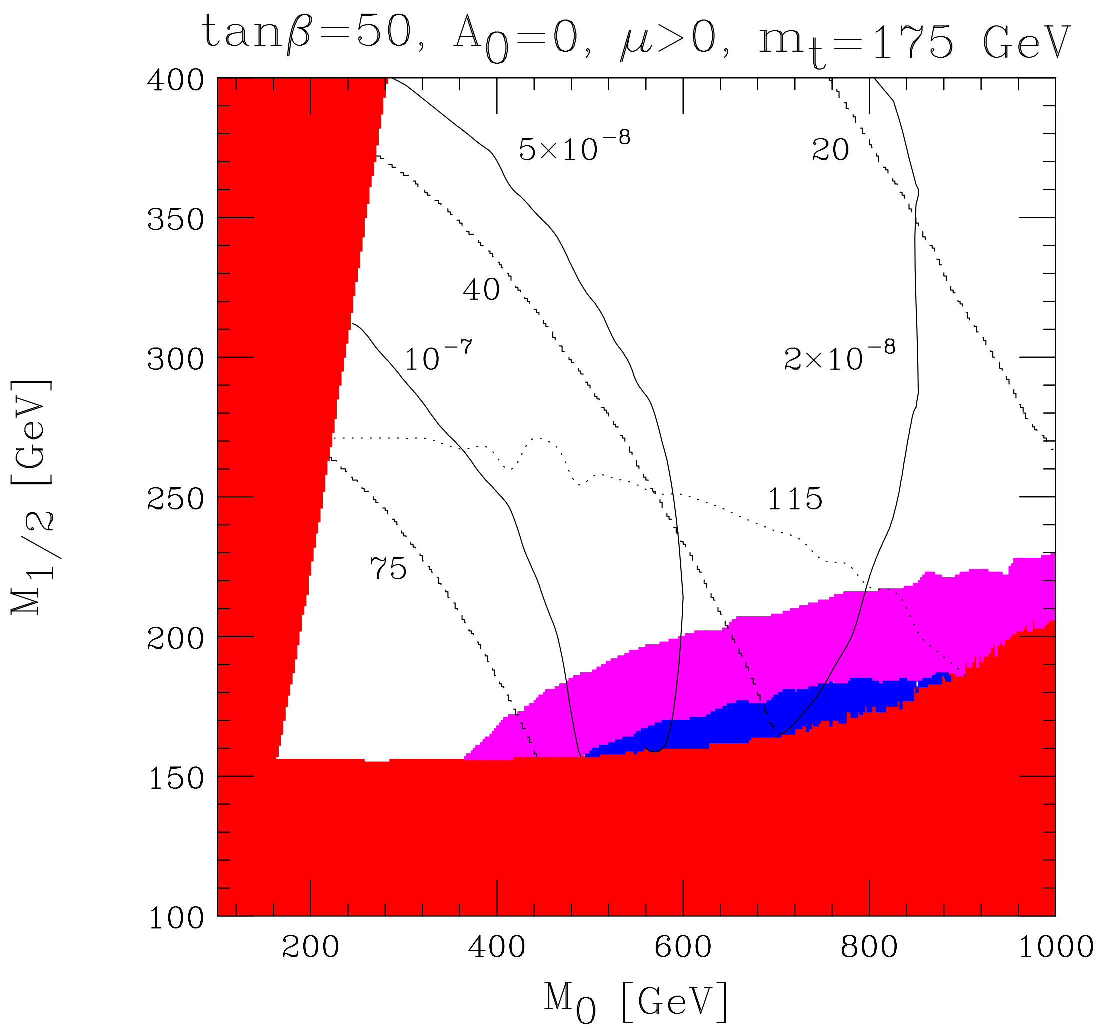
Dedes,Dreiner,Nierste,Richardson

- The rare B Decay $B \to X_s\gamma$ gives valuable information on the supersymmetric parameter space.
- In the future we can expect new constraints from $B_s \to \mu^+\mu^-$
- Currently there is a limit on the branching ratio $B(B_s \to \mu^+\mu^-) < 2.6 \times 10^{-6}$ from CDF.
- Because of the helicity suppression $B_s \to \mu^+\mu^-$ is sensitive to chirality flipping interactions in the extended Higgs sector.
- Important parameter: $\tan\beta =$ ratio of the two Higgs VEVs.

$\boxed{Br(B \to \ell^+\ell^-)}$

- probes the large $\tan\beta$ region better than any other B physics observable, with a possible enhancement over the SM by a factor of up to 1000, since $Br(B \to \ell^+\ell^-) \propto m_b^2 m_\ell^2 \tan^6\beta$.
- is most sensitive to effects from non-standard Higgs bosons,
- probes SO(10) GUT theories best,
- probes minimal supergravity scenarios (mSUGRA) through correlations with $(g-2)_\mu$ and the lightest Higgs boson mass,
- complements Tevatron searches for charginos/neutralinos through trilepton events.

Trilepton Events and $Br(B_s \to \mu^+\mu^-)$



Solid contour shows the prediction for the $Br(B_s \to \mu^+\mu^-)$ in the $M_0 - M_{1/2}$ plane for the mSUGRA scenario for large $\tan\beta = 50$,

Colored areas show the Tevatron 5σ reach in the trilepton channel with $A_0 = 0$, $\mu > 0$ and $m_t = 175$ GeV. Magenta: $30 fb^{-1}$, blue: $10 fb^{-1}$.

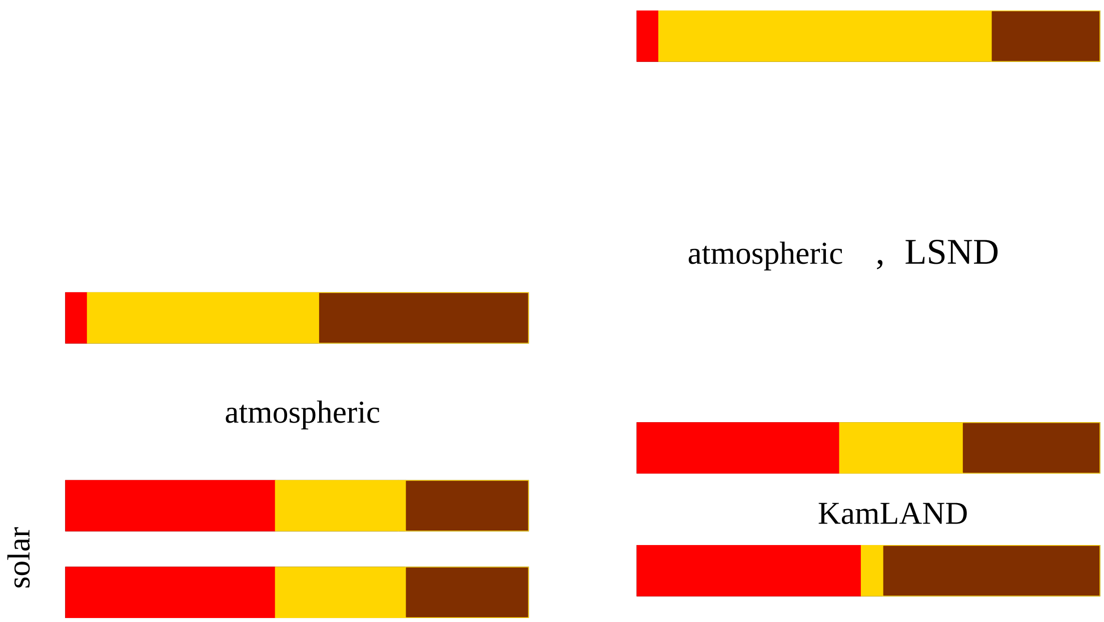
CPT violation in neutrino physics

Barenboim, Borissov, Lykken

- CPT conservation in the neutrino sector,
- two mass differences, three pieces of data
- Post-Kamland four main pieces of data with differing L/E scales
  - Solar $\nu_e \to \nu_e$ disappearance
  - Atmospheric (primarily) $\nu_\mu \to \nu_\tau$ disappearance
  - LSND $\bar{\nu}_\mu \to \bar{\nu}_e$ appearance
  - KAMLAND $\bar{\nu}_e \to \bar{\nu}_e$ disappearance

- With CPT violation in the neutrino sector we have independent mass matrices and mixing angles

- Hence two mass differences in the ν sector and two mass differences in the $\bar{\nu}$ sector

- 

- electron flavor (red), muon flavor (brown) and tau flavor (yellow)

- One more experiment will fix this, eg Minos observing a difference between ν and $\bar{\nu}$ atmospheric neutrinos.

Lattice gauge program

- Fermilab is the host for a user facility PC cluster which currently has 352 processors
- Facility is housed in the New Muon Lab. Large enough to handle up to 1000 dual-processor machines.
- Large collaboration, between University based users and strong in-house group.
- Focus is on topics which are important for the DOE program, ie CKM and Heavy quark physics (especially Babar, KTeV, Kami, CKM, B-physics at CDF and D0, BTeV)

Unquenched calculations

- Big progress in recent unquenched staggered fermion phenomenology.

- For simple enough quantities, deviations in quenched calculations from experiment disappear in unquenched calculations

- input parameters

  – $n_f = 3$, $a = 1/8$ fm and $1/11$ fm.

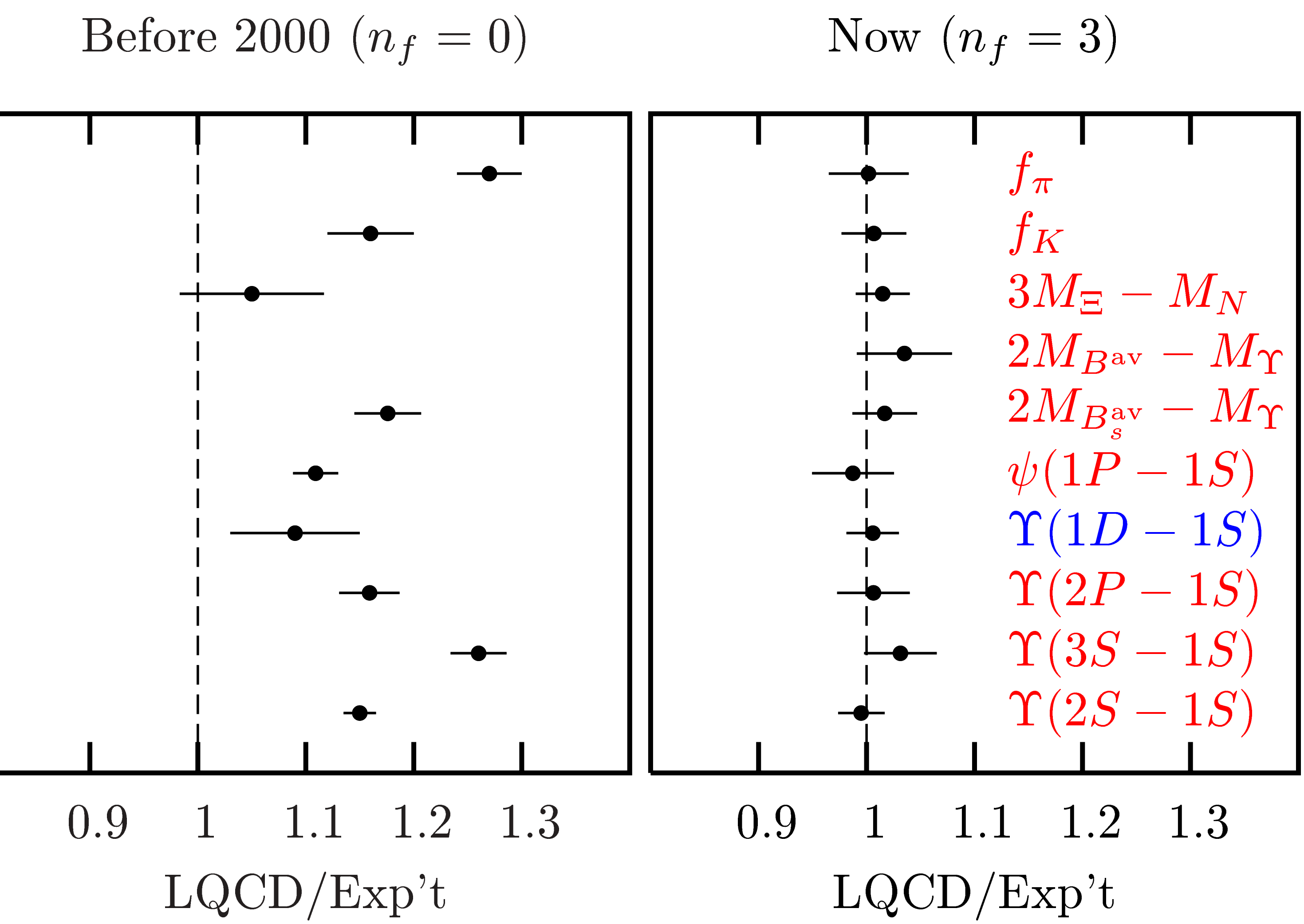
  – Tune $m_u = m_d$, m_s, m_c, m_b, and α_s using m_π, m_K, m_ψ, m_Υ, and $\Delta E_\Upsilon(1P1S)$.

- Output renormalized masses and couplings

  – $\alpha_{\overline{MS}} = 0.119(3)$

  – $m_s(2\text{ GeV}) = 80(20)$ MeV

Quenched vs. Unquenched



All data use improved staggered light quarks and a^2 improved gauge action, where available.

Most Accurate Quantities?

The best choices for high precision comparison with experiment are stable particle, one-hadron processes especially mesons.

- Unstable particles messy to interpret.

  E. g., the ρ-meson in $B \to \rho l \nu$,
  final state is two interacting pions in a finite volume.

- Multi-hadron final states are different in Minkowski and Euclidean space.

“Golden” Quantities of Lattice QCD

Masses, Leptonic and Semileptonic Decays, Mixings of

π, K, f_π, f_K, $K \to \pi l \nu$

D, D_s, D^*, D_s^*,

B, B_s, B^*, B_s^*,

ψ, η_c, χ_c

Υ, η_b, χ_b

Light B_c states.

Υ, ψ, K, $\pi \Rightarrow \alpha_s$, m_q

For CKM determinations:

$\frac{f_{B_d}}{f_{B_s}}\sqrt{\frac{B_{B_d}}{B_{B_s}}}$, $\frac{\Delta M_{B_d}}{\Delta M_{B_s}} \Rightarrow \frac{V_{td}}{V_{ts}}$

$f_{B_s}\sqrt{B_{B_s}}, \Delta M_{B_s} \Rightarrow V_{ts}$

$B \to D l \nu \Rightarrow V_{cb}$

$B \to \pi l \nu \Rightarrow V_{ub}$

$D \to \pi l \nu \Rightarrow V_{cd}$

$D \to K l \nu \Rightarrow V_{cs}$

Good prototype calculations exist for all already.

Lattice QCD and the CKM matrix

Every relevant CKM matrix element (as well as every relevant quark mass and α_s) can be measured from a process in this class.

$$\begin{pmatrix} \mathbf{V_{ud}} & \mathbf{V_{us}} & \mathbf{V_{ub}} \\ \pi \to l\nu & K \to \pi l\nu & B \to \pi l\nu \\ \mathbf{V_{cd}} & \mathbf{V_{cs}} & \mathbf{V_{cb}} \\ f_D & f_{D_s} & B \to D l\nu \\ D \to \pi l\nu & D \to K l\nu & \\ & & \\ \mathbf{V_{td}} & \mathbf{V_{ts}} & \mathbf{V_{tb}} \\ < B_d|\overline{B_d} > & < B_s|\overline{B_s} > & - \end{pmatrix}$$

$B \to \psi K_s \Rightarrow \sin(2\beta)$, don't need lattice.

ϵ_K

V_{cb}

The Fermilab lattice form factor is used for the PDG determination of V_{cb},

$$\frac{d\Gamma}{dw} = \frac{G_F^2}{4\pi^3}(w^2-1)^{1/2} m_{D^*}^3 (m_B - m_{D^*})^2 \mathcal{G}(w) |V_{cb}|^2 |\mathcal{F}_{B\to D^*}(w)|^2$$

where $w = v \cdot v'$ and $\mathcal{G}(1) = 1$.

$$\mathcal{F}_{B\to D^*}(1) = 0.913^{+0.024}_{-0.017} \pm 0.016^{+0.003+0.000+0.006}_{-0.014-0.016-0.014}$$

where the uncertainties stem, respectively, from statistics and fitting, HQET matching, lattice spacing dependence, the chiral extrapolation, and the effect of the quenched approximation.

Conclusions

- Fermilab theory group has a broad and influential research program.
- Fermilab post-docs go on to positions of influence elsewhere.
- The post-doctoral and associate scientist programs of the national labs supply much of the theoretical physics that engages with experiment.
- I would like to acknowledge the support which we have received from the directorate to support the post-doctoral and associate scientist programs.